Anisotropic Minerals

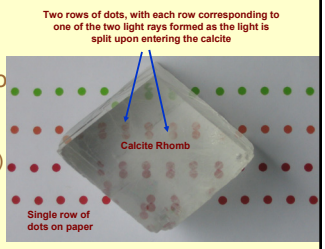
Chapter 5 or Nesse

Anisotropic Minerals

- Differ from Isotropic Minerals because:
  - The velocity of light _____ depending on the direction through the mineral, and
  - They exhibit _____

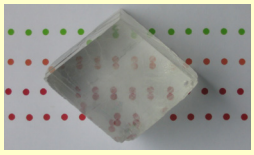
Anisotropic Minerals

- On entering an anisotropic mineral light is ____ into two rays that;
  - Have different _____ (and RI's)
  - Vibrate at _____ to each other



Double Refraction

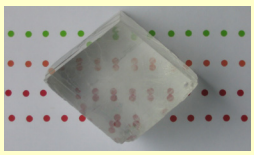
Calcite - What happens?

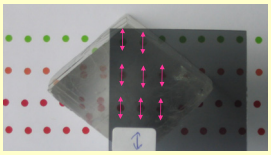


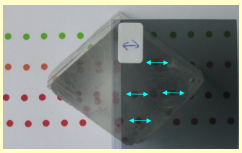
Each row of dots corresponds to one ray, each with its own _____ and ____.

Double Refraction

Calcite – Vibration Direction



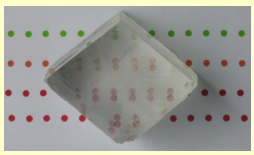


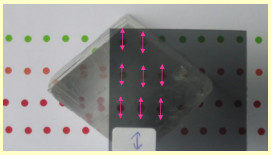


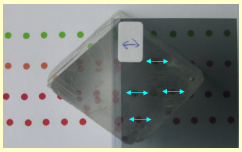
The **Vibration Direction** can be determined using a _____ _____.
The two rays are _____ _____ (have a single vibration direction) and _____ __ ___ to each other.

Double Refraction

Calcite – Refractive Index







The **RI** of each ray can be measured, using _____ ____.
One will be higher than the other.
The ray with the _____ **index** is called the ____ **ray**.
The ray with the _____ **index** is called the _____ **ray**.

Anisitropic Minerals

- There are one or two _____ through an anisotropic mineral along which light behaves as though the mineral were isotropic. This direction or directions are called the _____ _____
- Hexagonal and Tetragonal minerals have ___ optic axis and are termed **Uniaxial**
- Orthorhombic, monoclinic and triclinic minerals have ___ optic axes and are termed **Biaxial**

Anisitropic Minerals

CAUTIONARY NOTE

- Remember the difference between:
- Vibration direction – side to side oscillation of the electric vector of the plane light, and;
- Propagation direction – the direction the light is travelling

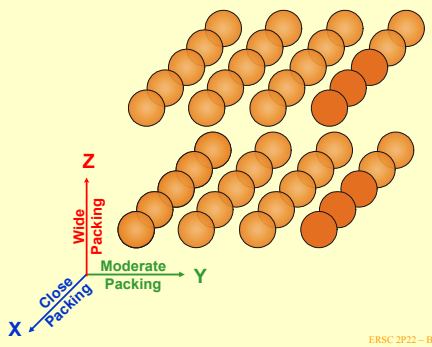
Why is Light Split?

- Electromagnetic theory provides insight as to why light is split and why the velocity of the light varies with direction through the anisotropic mineral
  - Strength of chemical bonds and atom density are different in different directions
  - A light ray will 'see' different electronic configuration depending on direction
  - The electron clouds around each atom vibrate with different frequencies in different directions

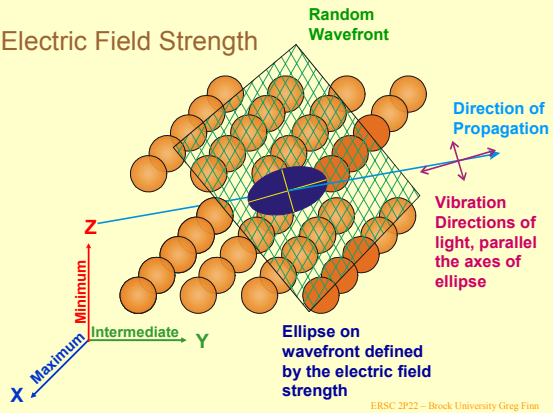
Why is Light Split?

- Velocity of light in an anisotropic mineral is dependant on:
  1. the interaction between the _____ of the electric vector of the light, and;
  2. the _____ of the electron clouds.
- Resulting in a variation in _____ with direction.
- _____ theory can explain why light is split into two rays, each with a different velocity, which vibrate at 90°

Atomic Packing



Electric Field Strength



Anisotropic Minerals

- The resulting two rays encounter different electronic configurations therefore their velocities and indices of refraction must be different

$$n = \frac{v_{vac}}{v_{medium}}$$

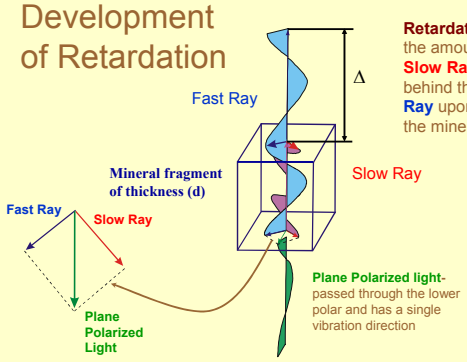
Anisotropic Minerals

- There will be one or two _____ in anisotropic minerals which show uniform electron configurations, resulting in the EFS plotting as a _____ rather than an _____
- Lines at _____ to this plane or planes are called the **Optic Axis** –
  - _____ _____ (the mineral behaves as an isotropic mineral)

Interference Phenomena

- Under crossed polars anisotropic minerals display a variety of colours – _____ which are produced as a consequence of the light being _____ into two rays on passing through the mineral
- Examine interference phenomena using monochromatic light and apply the concepts to polychromatic (white) light

Development of Retardation



Retardation (Δ) – the amount that the **Slow Ray** lags behind the **Fast Ray** upon existing the mineral

Plane Polarized light- passed through the lower polar and has a single vibration direction

Development of Retardation

- Magnitude of the retardation is dependant on:
  - The _____ of the sample (d)
  - The _____ in velocity of the slow (V_s) and fast (V_f) rays

Development of Retardation

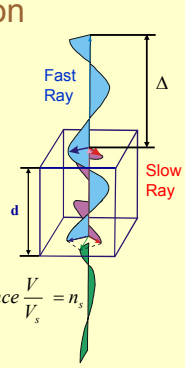
$$t_s = \frac{d}{V_s}$$

Time it takes for the slow ray to pass through the mineral

$$t_s = \frac{d}{V_f} + \frac{\Delta}{V}$$

where V = velocity in air

Time for the fast ray to pass through the mineral



$$\frac{d}{V_s} = \frac{d}{V_f} + \frac{\Delta}{V} \Rightarrow \Delta = d\left(\frac{V}{V_s} - \frac{V}{V_f}\right) \quad Since\ \frac{V}{V_s} = n_s$$

$$\Delta = d\left(n_s - n_f\right)$$

Development of Retardation

$$\Delta = d\left(n_s - n_f\right)$$

- Relationship ($n_s - n_f$) is termed _____ **(δ)** and represents the difference in the indices of refraction of the slow and fast rays
- In anisotropic minerals one path, along the optic axis, exhibits ____ birefringence, others show a _____, but most show an _____ value
- Maximum Birefringence is characteristic for each mineral
- Birefringence _____ with wavelength of light

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QUESTION

We have just observed that upon entering a mineral, light is split into two rays - Fast and Slow

What happens to the two rays of light (Slow and Fast rays) after they have exited the mineral grain?

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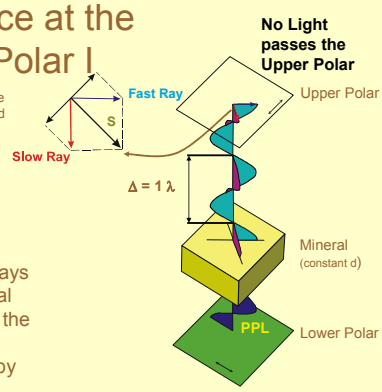
Interference at the Upper Polar I

When vector components of the **slow** and **fast** rays are resolved into the vibration direction of the upper polar they are in opposite directions and cancel, so no light passes. The vector **S**, the sum of the two waves, is at right angles to the polars vibration direction.



The **fast** and **slow** rays on exiting the mineral are **IN PHASE**, with the **slow** ray lagging behind the **fast** ray by 1 whole wavelength

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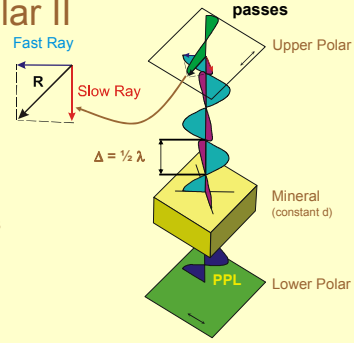
Interference at the Upper Polar II

Vector components of the **slow** and **fast** rays resolved into the vibration direction of the upper polar are in the same direction, so they constructively interfere to yield **R**, which passes the upper polar and the mineral appears bright.



The **fast** and **slow** rays on exiting the mineral are **OUT OF PHASE**, with the **slow** ray lagging behind the **fast** ray by ½ wavelength

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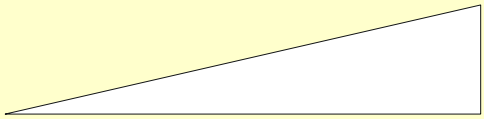
Interference at the Upper Polar

- In the two cases examined, the sample was a constant thickness and exhibited a constant retardation
- If our sample is _____ shaped, the thickness and therefore the retardation will _____ along the length



Δ – Varies along the length ==➔

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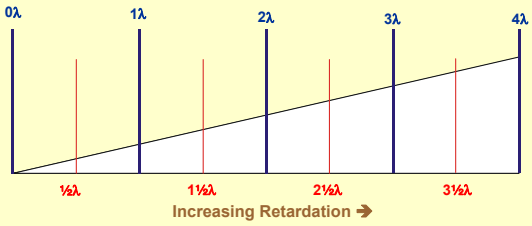
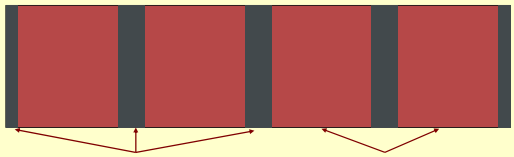
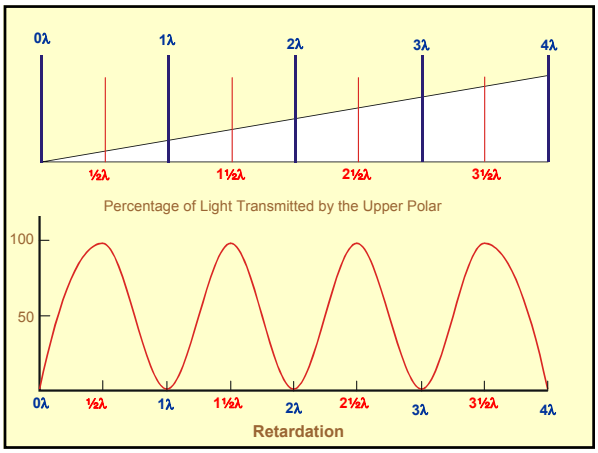


Quartz Wedge viewed between crossed polars under Red Light





Polychromatic or White Light

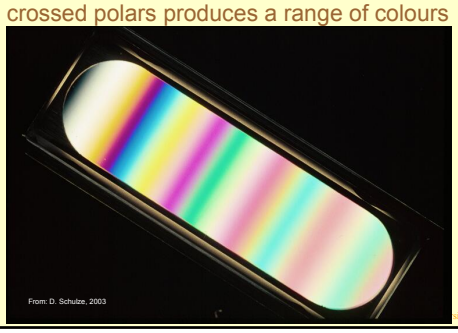
- Light of a variety of wavelengths, each of which is split into a slow and fast ray, the retardation is the same for all wavelengths
- Due to different wavelengths, some reach the upper polar _____ and are cancelled, while others are _____ and are transmitted through the upper polar
- The combination of wavelengths that pass the upper polar produces the _____ _____

Polychromatic or White Light

- Interference colours depend on the retardation of the slow and fast ray, which reflects:
  - _____, and
  - _____
- Samples of the same mineral will display different interference colours, depending on thickness and the orientation of the sample

Polychromatic or White Light

- Examining the quartz wedge between crossed polars produces a range of colours



Polychromatic or White Light

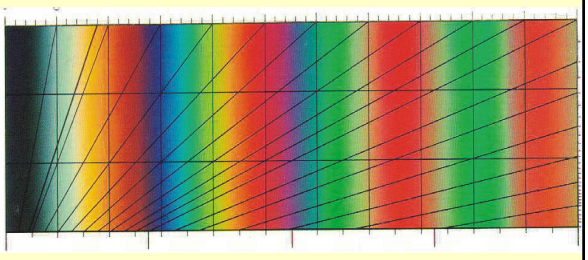
- At the thin edge , thickness and retardation are ~ 0, all wavelengths of light are cancelled at the upper polar, so colour is black
- With increasing thickness colour changes from:

  black to **grey** to **yellow** to **red** and then a repeating sequence from **blue** to **green** to **yellow** to **red**

  – With each repetition the colours become paler

Michel-Levy Colour Chart

Quartz wedge viewed between crossed polars

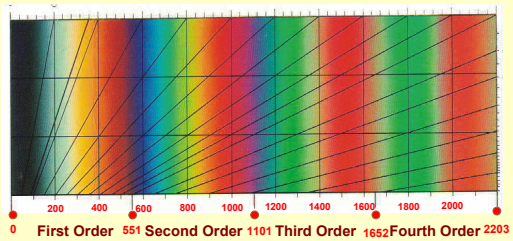


Order of Interference Colours

- On the colour chart, the repetition of interference colours, from red to blue occurs at retardations of 550, 1100, 1650 and 2200 nm
- Boundaries are used to separate the colour sequence into orders
- 1st and 2nd order colours are vivid
- Higher order colours become progressively more washed out, beyond 4th order the colours become a creamy white

Michel-Levy Colour Chart

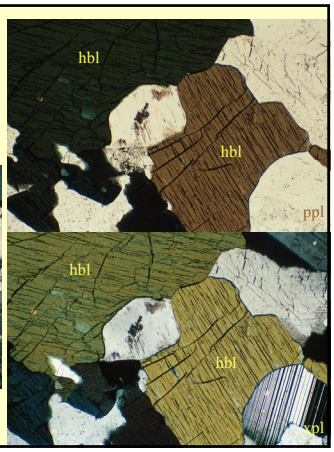
Retardation (Δ)



Anamolous Interference Colours

- Colours under crossed polars that _____ appear on the colour chart
- Colours result when birefringence and retardation are significantly _____ for different wavelengths of light, resulting in a different complement of wavelengths passing the upper polar, which is perceived as a different interference colour
- Mineral colour also influences interference colour as some wavelengths of light are selectively absorbed by the mineral
  - Green minerals transmit green light, absorb others, resulting in interference colours with a greenish tint

Anomalous Interference Colours

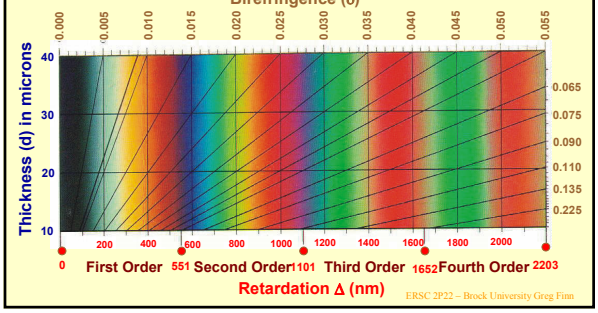


All images from D. Schulze, 2003

Michel-Levy Colour Chart

Relates: Thickness (d) Retardation (Δ) Birefringence (δ)

$$\Delta = d(n_s - n_f)$$



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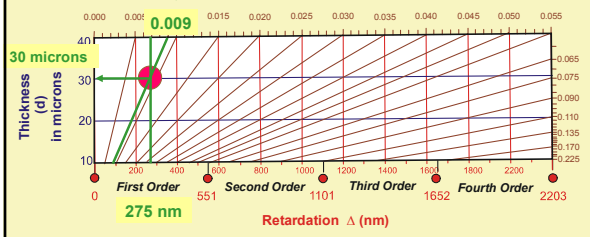
Determining Thickness

of a known mineral (Quartz)

Relationship between Thickness (d), Birefringence (δ) and Retardation (Δ)

Mineral is Quartz Birefringence $\delta = (n_s - n_f)$



1st order grey, just a hint of yellow

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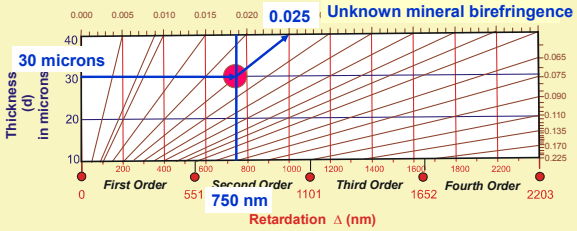
Determining Birefringence

of an unknown mineral

Relationship between Thickness (d), Birefringence (δ) and Retardation (Δ)

Birefringence $\delta = (n_s - n_f)$



Max Birefringence - 2nd order yellow, with a hint of green

Recognizing the Order of the Interference Colour

- Becomes easier with practice and familiarity
  - eg. Distinguishing 2nd order red from 4th order red
- Coloured grains may mask the interference colour
- Look at grain edges vs centres
- 1st order white vs high-order white